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(54) Method and apparatus for contactless rotational speed measurement

(57) An electromagnetic system using a Doppler transceiver for the control and monitoring of the rotation speeds of various objects such as turbines. A digital readout of the revolutions per minute of the object is produced and thumb wheel counters are utilized to provide a maximum speed reference, which if exceeded, initiates a pulse to activate a solid state relay for governor control. The system described is effective over RPM ranges of 250 to 30,000 RPM and the accuracy of speed measurement within plus or minus one-half percent. The range can be readily be increased by using additional circuitry.

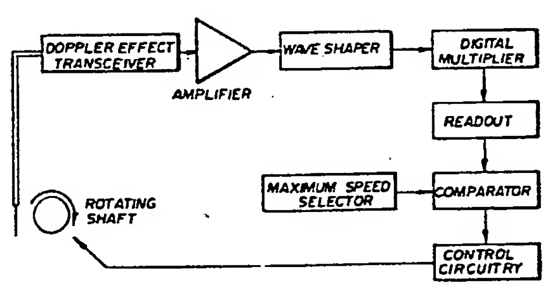

FIG. 1

The drawing(s) originally filed was/were informal and the print here reproduced is taken from a later filed formal copy.

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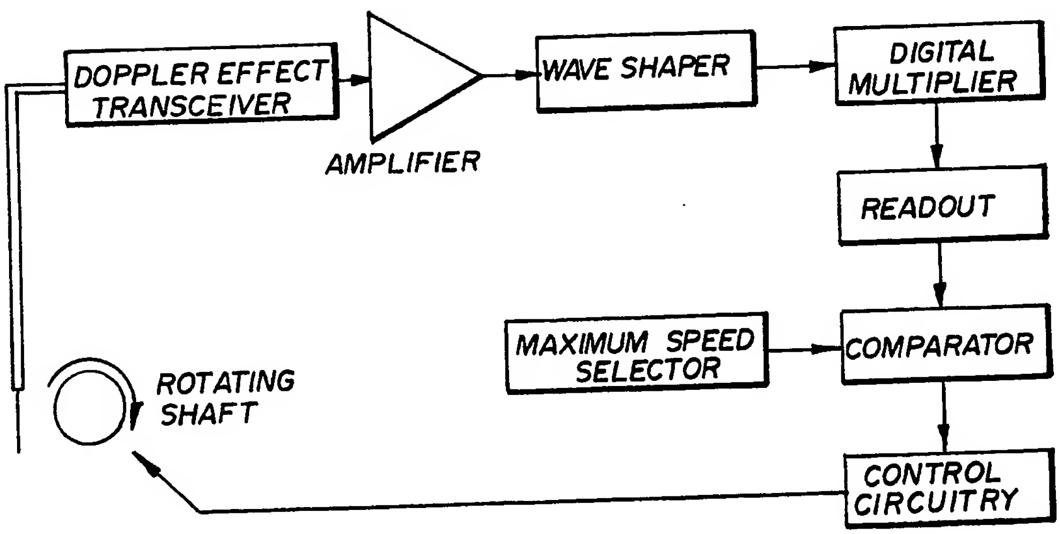

FIG. I

SPECIFICATION

Method and apparatus for contactless rotational speed measurement

This invention is directed to a Doppler radar technique for monitoring the revolutions per minute of rotating objects. More particularly, this invention is directed to a contactless system for the monitoring of the revolutions per minute of the shaft of a gas turbine using a Doppler radar technique.

BACKGROUND OF THE INVENTION

Presently used methods of monitoring the revolutions per minute of rotating objects such as gas turbines rely upon the use of devices or systems which are physically coupled to the turbine through moving parts. Becauss physical wear is involved, the devices and systems wear out in time, require maintenance to correct errors, and frequently need replacement. Some systems are coupled to the rotating object through moving parts, other systems involve the use of rotary transformers, and still other systems utilize magnetic pickups. Although all of these techniques are effective in their own right, and for the purposes required, they all have shortcomings.

The use of rotary transformers is frequently satisfactory, but the cost of additional equipment makes these techniques expensive. Magnetic pickup systems are also useful but suffer from installation problems and high cost. Stroboscopes are often used to synchronize a flashing light with the shaft rotation, making the shaft appear stationary. While this instrument offers a non-contacting method of rotational velocity measurement, thereby eliminating wear of moving parts, it has the disadvantage of being able to synchronize on harmonics of the fundamental shaft speed, thus requiring the user to know the apoproximate velocity at which the object, e.g. shaft, is rotating in order to avoid error. While the stroboscope lends itself to discrete monitoring, it is impractical for continuous monitoring or speed control.

SUMMARY OF THE INVENTION

The inventors have developed a non-contact method for measuring and monitoring the speed of rotation of a rotating object such as the shaft of a gas turbine which has reliablity and accuracy, requires an insignificant alteration to existing installations and is economical to install. The contactless method of monitoring the rotation of the rotating object such as a gas turbine shaft is done utilizing a Doppler radar technique which involves no moving parts and has solid-state reliability.

The principle of operation is based on the shift in frequency resulting from the reflection of a radio signal from a moving body. The frequency difference provides a direct correlateable indication of the speed of the moving body, for example, a rotating turbine shaft. When a rotating object such as a turbine shaft is beamed at an angle to the axis by a Doppler type radar, the presence of any mechanical imbalance in the shape of the rotating object (e.g. shaft) for example balancing holes, screws, keyways, slots or protrusions, surface roughness, etc. gives rise to bursts of Doppler signals which can be readily identified and evaluated by signal processing. Any beam angle will work and the strength of the returned signal is roughly proportional to the cosine of the angle. According to experimented evidence, a beam angle of 90° may not necessarily be optimum – the optimum angle is dependent on shaft discontinuity geometry. Each revolution of the object produces an identical pattern and these may be monitored using a counter to read the revolutions per minute of the object (e.g. turbine shaft).The degree of electrical imbalance required to give a useful signal is very small and one can usually rely on normal surface roughness of the object to give adequate reflection for satisfactory operation of the technique, unless discontinuities exist which give larger bursts of a return signal.

The invention is characterized by (a) a digital readout in revolutions per minute, (b) thumb wheel set counters for providing a maximum speed control reference, (c) thumb wheel set counters which initiate a pulse to turn on solid state relay capable of delivering 120 volts at 5 amps for governor control, and (d) an ability to monitor revolutions per minute ranging from 250 to 30,000 revolutions per minute with an accuracy of measurement exceeding ± 1/2%. The range can be readily increased by using additional circuitry.

The invention is directed to a method of measuring, controlling and monitoring the rotational speed of a rotating object comprising employing a Doppler effect transreceiver to measure the rotation speed of the rotating object, feeding the signal from the Doppler transceiver into an amplifier, subsequently into a wave shaper, subsequently into a digital multiplier, subsequently into a readout and comparator, and finally into control circuitry which, if the rotational speed of the object exceeds a predetermined speed, shuts down the object.

The invention also includes a method of measuring, monitoring and controlling the rotational object speed by utilizing a Doppler transceiver which detects discontinuities on the surface of the rotating object, whereby the audio output of the Dopper transceiver is amplified and is then fed into a wave shaper which eliminates the harmonics, renders the signal compatible with logic being used in the system, the signal being multiplied by a digital frequency multiplier and being fed into a readout, the frequency of the signal being fed into the readout whereby it is monitored by a comparator, and if the frequency exceeds a predetermined set point, the comparator produces a pulse which is utilized to activate speed control circuitry attached to the rotating object. A 3 milli watt transceiver can be used. The output of the transceiver can be directed onto the rotating object by a horn, or an antenna system, and can be shielded to prevent the movement of objects other than the rotating object being monitored from affecting the transceivers electromagnetic field.

A method of determining the rate of rotation of a rotating object comprising utilizing an electronic measuring means based on the Doppler effect for transmitting a signal for reflection off a rotating ob-

ject and receiving the signal reflected from the rotating object and mixing the signal to produce an audio signal of the rotating body.

The output signal from the Doppler measuring unit can be amplified to 5 V peak whereby it is easily shaped for TTL compatibility using a one shot and is reduced to a fundamental harmonic by a frequency divider circuit. The method can employ amplifier/wave shaper means to produce one pulse per revolution and such pulses are counted for one second utilizing an X 60 multiplier means.

Multiplication can be accomplished by dividing the period of the incoming frequency by the multiplicand, a 10 MHz pulse strain being gated by the incoming frequency into a counting circuit, the accumulated pulse count, for one period being then divided by the multiplicand and being fed into a down counting circuit clocked at 10 MHz, the resulting output frequency therefore being greater according to the multiplicand ratio than the incoming frequency.

A digital readout means can be used whereby the multiplier is divided into three decades to reduce resolution error. The readout value can be compared with a thumb wheel switch means value preset by means of digital circuitry, and if the readout value exceeds the set on the thumb wheel switch, a latch relay means can be pulsed which in turn closes a set of contacts to shut down the rotating object.

The invention is directed to a Doppler transceiver (e.g. an X-band Doppler transceiver) used for measuring, controlling and monitoring the rotational speed of various objects (e.g. turbines). The invention includes an electromagnetic system for measuring, controlling and monitoring the rotational speeds of objects comprising in combination (1) a Doppler transceiver, (2) an amplifier/wave shaper circuit, (3) a multiplier, (4) a readout system and (5) a comparator.

A shutdown actuator can be incorporated into the system. The circuits can be sub-divided into boards counting 3 to 5 IC's per board.

DRAWINGS

In the drawings:

FIGURE 1 represents a block diagram of a digital readout tachometer.

DETAILED DESCRIPTION OF THE INVENTION

A transceiver, while mainly used in the past for the measurement of linear velocities, is utilized for the measurement of rotational velocities. The module transmits a microwave signal, and mixes the signal reflected from a linearly moving or rotatinally moving object to produce an audio signal whose period is inversely proportional to either the linear or the rotational speed of the object being observed. This signal is then processed by analog and digital circuitry to give the desired readout.

For angular velocity measurment, the transceiver is used to detect discontinuities on the surface of the rotating member, e.g., shaft surface. Even minute discontinuities on a rotating member have been shown to produce audio signals. Using a 3 mW transceiver, signals of the order of tens of mV-peak have been measured from a machined shaft and in the order of tens of μV-peak from a rotating hexagonal nut.

The main advantage of using a Doppler transceiver system is that it is non-contacting. The rotating member e.g. turbine shaft, does not have to drive any mechanisms, and no modifications have to be made to the member, that is, the attachment of magnets or reflective tape. The output of the transceiver merely has to be directed onto the member via a horn, or other antenna system, and shielded to prevent the movement of objects other than the member being monitored from affecting the transceivers electromagnetic field and introducing extraneous signals. The economics of using a Doppler transceiver also make it attractive over other RPM measuring devices available on the market.

Since the receiver detects discontinuities on the rotating surface, the only real disadvantage of this system is that the readout may be a multiple of the actual velocity of the rotating member. This problem is easily overcome by using analog circuitry to eliminate the lower level discontinuity signals and then using digital circuitry to eliminate whatever harmonics are left. However, the unit must be individually calibrated for each shaft to be monitored.

As shown in Figure 1 (which shows a block diagram of the digital readout tachometer) the audio output of the Doppler transceiver is amplified and is then fed into the wave shaper which eliminates and is then fed into the wave shaper which eliminates the harmonics as described previously, and makes the signal compatible with the logic being used. The signal is then multiplied by a digital frequency multiplier and is fed into a readout. The frequency of the signal being fed into the readout is monitored by a comparator. If this frequency exceeds a predetermined set point, the comparator produces a pulse which is used to activate the turbines speed control circuitry.

TTL was used to construct the logic, however other types of logics such as CMOS could alsm have been used. It is also conceivable that a CPU could have been used in place of the logic.

The Doppler transceiver that has been used is a preconstructed microwave device that is now commonly available on the electronics market-place. The Doppler transceiver transmits a signal in the 10 GHz region, receives the reflected signal and mixes the signals to produce an audio signal whose frequency is proportional to the linear or rotational speed of the moving or rotating body at which its transmitted beam is directed, and is also proportional to the number of discontinuities on the surface of the rotating body. Even minute surface discontinuities produce measurable audio signals.

A low noise amplifying circuit is required since the output signal of the Doppler transceiver unit in some cases may be quite small (10uV peak). Once the signal is amplified to 5V peak, it is readily shaped for TTL compatibility using a one shot and is reduced to its fundamental harmonic by a frequency divider circuit. Any frequency Doppler module may be used.

The system also uses an amplifier/wave shaper

which produces one pulse per revolution of the rotating member e.g. turbine shaft. To obtain a readout in revolutions per minute, it would normally be necessary to count pulses for one minute. This is a rather long and impractical counting time and was considered by the inventors to be potentially detrimental. This was so because any circuit used to detect excessive speed of the member e.g. turbine shaft (overspeed detector) would be connected to the counting circuit and there was therefore the possibility of the turbine, for example, running a full minute at an excessive and possibly dangerous speed before the shut down sequence would be initiated. A more reasonable solution would be to count for only one second, thus requiring an x60 multiplier.

A computerized study showed that it would be best to divide the meter range into three decades, 30. to 300, 300 to 3,000 and 3,000 to 30,000 RPM. The multiplier was assigned a different multiplicand for each decade: 600 for 30 to 300, 60 for 300 to 3,000 and 6 for 3,000 to 30,000. The result of this decadization was to assure a maximum quantitization error of 0.1 percent in the multiplier. This technique also reduced the resolution error in the readout.

The multiplication can be accomplished readily by diving the period of the incoming frequency by the multiplicand. A 10 MHz pulse train is gated by the incoming frequency into a counting circuit. The accumulated pulse count for one period is then divided by the multiplicand (M) and fed into a down counting circuit clocked at 10 MHZ. The resulting output frequency will then be M times greater than the incoming frequency.

The invention also uses a readout which consists of six digits (00000.0). The multiplier, as explained previously, is divided into three decades to reduce resolution error. The reduction in resolution error can be accomplished as follows: whenever a digital readout is used, there is always an uncertainty in the last digit. Using the three decade system, the first decade (30 to 300) has a resolution of ±0.1 RPM (0.33% maximum). The second decade (300 to 3,000) has a resolution of ±1 RPM (0.33% maximum). The third decade (3,000 to 30,000) has a resolution of ±10 RMP (0.33% maximum). The third decade cannot have its resolution reduced to ±1 RPM without increasing the multiplier quantization error beyond acceptable limits.

Finally, the system utilizes a comparator and a shut-down actuator. The readout value and thumb wheel switch valves can be compared quickly and easily utilizing digital circuitry. If the readout value exceeds that set on the thumb wheel switches, a latching relay is pulsed, closing a set of contacts to initiate the shut-down sequence. The maximum delay between overspeed occurrence and shut-down initiation will be one second. Normally, no significant damage to the rotating member e.g. turbine can occur in one second. The latching relay is manually reset once the shut-down has been initiated.

To facilitate easy repair and maintenance in the field, the circuits are sub-divided into a number of small boards, each counting from 3 to 5 IC's per board. Edge connectors can be used to enhance maintenance and repair.

The system described above has been bench tested at the University of Regina, Regina, Saskatchewan, Canada, and has been found to be very successful. The range of the monitor is easily extended and probably can be adapted into a handheld tachometer by using memory chips, etc. The system has been found to be reliable and has resulted in a considerable cost saving over the mechanical system previously used at this station.

While particular embodiments of the present invention have been shown and described, it is apparent that various changes and modifications may be made, and it is therefore intended in the following claims to cover all such obvious modifications and changes as may fall within the true spirit and scope of this invention.

CLAIMS

1. A contactless method of measuring, controlling and monitoring the rotational speeds of rotating members by using a Doppler transceiver.

2. A method of measuring, controlling and monitoring the rotational speed of a rotating member comprising employing a Doppler effect transceiver to measure the rotation speed of the rotating member, feeding the signal from the Doppler transceiver into an amplifier, subsequently into a wave shaper, subsequently into a digital multiplier, subsequently into a readout and comparator, and finally into control circuitry which, if the rotational speed of the member exceeds a predetermined speed, shuts down the member.

3. A method of measuring, monitoring and controlling the rotational shaft speed of a turbine by utilizing a Doppler transceiver which detects discontinuities on the surface of the rotating shaft of the turbine, whereby the audio output of the doppler transceiver is amplified and is then fed into a wave shaper which eliminates the harmonics, renders the signal compatible with logic being used in the system, the signal being multiplied by a digital frequency multiplier and being fed into a readout, the frequency of the signal being fed into the readout whereby it is monitored by a comparator, and if the frequency exceeds a predetermined set point, the comparator produces a pulse which is utilized to activate speed control circuitry attached to the turbine.

4. A method according to claim 3 wherein a 3 milliwatt transceiver is used.

5. The method of claim 4 wherein the output of the transceiver is directed onto the rotating shaft by a horn, or an antenna system, and is shielded to prevent the movement of objects other than the rotating shaft being monitored from affecting the transceiver's electromagnetic field.

6. A method of determining the rate of rotation of a rotating object comprising utilizing an electronic measuring means based on the Doppler effect for transmitting a signal for reflection off a rotating object and receiving the signal reflected from the

rotating object and mixing the signal to produce an audio signal with a frequency proportional to the rotational speed of the rotating body.

7. The method of claim 6 wherein the output signal from the Doppler measuring unit is amplified to 5 V peak whereby it is easily shaped for TTL compatibility using a one shot and is reduced to a fundamental harmonic by a frequency divider circuit.

8. The method of claim 7 wherein amplifier/wave shaper means are utilized to produce one pulse per revolution and such pulses are counted for one second utilizing an X 60 multiplier means.

9. The method of claim 8 whereby multiplication is accomplished by dividing the period of the incoming frequency by the multiplicand, a 10 MHz pulse strain being gated by the incoming frequency into a counting circuit, the accumulated pulse count for one period being then divided by the multiplicand and being fed into a down counting circuit clocked at 10 MHz, the resulting output frequency thus being greater according to the multiplicand ratio than the incoming frequency.

10. The method of claim 9 whereby a digital readout means is used such that the multiplier is divided into three decades to reduce resolution error.

11. The method of claim 10 wherein the readout value is compared with a thum wheel switch means value preset by means of digital circuitry, and when the readout value exceeds the value set on the thumb wheel switch, a latch relay means is pulsed which in turn closes a set of contacts to shut down the rotating object.

12. A Doppler transceiver used for measuring, controlling and monitoring the rotational speed of a rotating object.

13. An electromagnetic system for measuring, controlling and monitoring the rotational speed of a rotating object comprising in combination (1) a Doppler transceiver, (2) an amplifier/wave shaper circuit, (3) a multiplier, (4) a readout system and (5) a comparator.

14. The system of claim 13 wherein the transceiver is a 3 milliwatt transceiver.

15. The system of claim 14 wherein the amplifier/wave shaper produces one pulse per rotation of the rotating object.

16. The system of claim 15 wherein a x60 multiplier is used in the system.

17. The system of claim 13 wherein a shut down actuator is incorporated into the system.

18. The system of claim 15, 16 or 17 wherein circuits are sub-divided into boards counting 3 to 5 IC's per board.

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